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NRL Memorandum Report 4196

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**Sonar Transducer Reliability
Improvement Program FY 80**

Second Quarter Progress

R. W. TIMME

Materials Section

Transducer Branch

Underwater Sound Reference Detachment

P.O. Box 8337, Orlando, FL 32856

April 1, 1980



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Progress accomplished during the second quarter of FY80 in the Sonar Transducer Reliability Improvement Program is reported. Each of the six major task areas is discussed in some detail. The most significant aspects include continued investigation of candidate fill-fluids for transducers; information gained from CUALT on the TR-316 projector which had immediate application to the TR-242 projector of the AN/BQS-15 system; results of CUALT performed on 2 DT-605 hydrophones which simulated 2 years of life service; new starts made in Tasks C-1 and F-3; and the annual STRIP review which was held on 11 & 12 March 1980.		

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Sonar Transducer Reliability Improvement Program
NRL Problem 0584
FY80 Second Quarter Progress Report

1. INTRODUCTION

1.1. PROGRAM OVERVIEW

The general objective of this program is to perform relevant engineering development which addresses the operational requirements for fleet transducers for active sonar, passive sonar, surveillance, counter-measures and deception devices, navigation, and acoustic communications. The approach is to develop, test, and evaluate improved transducer design, materials, components, and piece parts that will meet specified requirements in the operational environment during the entire useful life of the transducer. Standards will be prepared to ensure that results obtained during preliminary testing will be obtained consistently in production. This program should result in improved performance and reliability and reduced costs through better utilization and a more comprehensive characterization of materials and design data. The program goals are as follows:

- Reduction in transducer replacement costs
 - Goal - less than 9% of population replaced each year with no automatic replacements at overhaul.
 - Threshold - less than 18% of population replaced each year.
- Improvement in transducer reliability
 - Goal - less than 1% of population failures each year.
 - Threshold - less than 3% of population failures each year.
- Improvement in transducer receiving sensitivity
 - Goal - less than ± 1 dB variation from the specified value over operational frequency band.
 - Threshold - less than ± 2 dB variation from the specified value over operational frequency band.

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The Sonar Transducer Reliability Improvement Program (STRIP) is a part of Program Element 64503N. Major task areas with specific objectives to achieve the program goals have been described in the Program Plan and include:

Task Area A. Encapsulation Methods
 Task Area B. High Voltage Engineering
 Task Area C. Cables and Connectors
 Task Area D. Transducer Material Standards
 Task Area E. Environmental Test Methods
 Task Area F. Transducer Tests and Evaluation

The FY80 Program Plan for STRIP has been funded at the \$495 K level. The specific tasks and their Principal Investigators for FY80 are listed below:

	<u>TASK</u>	<u>PRINCIPAL</u>	<u>INVESTIGATOR</u>
A-1	Fluids and Specifications	NRL	C.M. Thompson
B-1	Corona Abatement	NRL	L.P. Browder
C-1	Handbook for Harness Design	GD/EB	R.F. Haworth
C-2	Standard for O-Ring Installation	APL/University of Washington	C.J. Sandwith
C-3	Cable and Connectors	TRI	D.E. Glowe
D-1	Alternative Materials - Plastics	NWSC	D.E. Moore
D-2	Pressure Release Materials	NUSC	C.L. LeBlanc
E-1	CUALT	NOSC	J. Wong
E-2	ALT Verification	NWSC	D.E. Moore
F-1	Failure Modes due to Water	TRI	D. Barrett
F-2	Shock Hardened Pressure Release	Westinghouse	C.J. Wilson
F-3	Reliability & Life Prediction Specification	TRI	R.L. Smith
F-4	Engineering Documentation	NRL	R.W. Timme

1.2. SUMMARY OF PROGRESS

During the second quarter of FY80, efforts in the various tasks of STRIP have resulted in progress toward the program goals as summarized below:

- A continuing investigation of candidate fill-fluids for transducers has shown that tricresyl phosphate has

promise for use where a careful selection of rubber is possible. See Section 2.3.

- Information gained from the Composite Unit Accelerated Life Test (CUALT) on the TR-316 has had immediate application to the TR-242 projector of the AN/BQS-15 system and has resulted in a more reliable fleet operational transducer. See Section 9.3.3.
- CUALT has been performed on two DT-605 hydrophones to simulate two years life service. The hydrophones are still completely within specification. No design problems have been found; testing continues.
- New starts for FY80 have been made in Task C-1 (see Section 4) - Handbook for Connector and Cable Harness Design, by General Dynamics/Electric Boat, and in Task F-3 (see Section 13) - Reliability and Life Prediction Specification, by Texas Research Institute.
- The annual review for the STRIP was held on 11 and 12 March 1980 at the Naval Research Laboratory, Washington, DC. The 55 in attendance represented a cross section of the sonar community — program managers, sonar engineers and designers, transducer restoration engineers, and scientists:

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1.3. PLANS

The Program Plan for the FY81 STRIP is currently being reviewed and will be presented to NAVSEA in May 1980.

1.4. REPORT ORGANIZATION

The remaining sections of this quarterly report will discuss the objectives, progress, and plans for the specific tasks included in the STRIP.

2. TASK A-1 - TRANSDUCER FLUIDS AND SPECIFICATIONS

C.M. Thompson - NRL-USRD

2.1. BACKGROUND

A material to be used for filling a sonar transducer must meet a wide variety of specifications. The requirements imposed by the electrical nature of the device include high resistivity, high dielectric constant, as well as resistance to corona and arc discharges. The water environment of the transducer necessitates low water solubility and other attractive solution properties. In addition, the fluid must maintain its electrical and other properties in the presence of any water which permeates the covering. The acoustic requirements are a close acoustic impedance match with seawater and resistance to cavitation at high-drive levels. Other obvious properties include compatibility with other components, stability to degradation, suitable surface tension, and viscosity.

With such a wide variety of requirements, it is not surprising that compromises have to be made. The most commonly used fluid for many years has been castor oil. This use is in spite of its high viscosity. Each of the fluids proposed, so far, as a replacement has serious drawbacks. Silicone oils tend to creep onto and wet all of the surfaces of the transducer. This greatly complicates bonding the components together. Polyalkylene glycol (PAG) has the disadvantages of a high water solubility and low electrical resistivity. The various hydrocarbon liquids have too low an acoustic impedance and are frequently incompatible with the various plastics and rubbers in the transducer. Further research is necessary to find and qualify fill-fluids which represent the best match to all the requirement imposed upon it.

2.2. OBJECTIVES

The objectives of this task are:

- To find plausible new transducer fill-fluids which combine the best properties. Candidates include: hydrophobic-polyethers, sterically protected esters, chlorine - or fluorine - containing hydrocarbons, and possibly aromatic hydrocarbons.
- To apply the criteria developed during the PAG and castor oil testing to the most promising candidate fluids.

2.3. PROGRESS

2.3.1. Tricresyl phosphase (TCP) was discussed in the STRIP FY80 First Quarter Report [1] as a sonar transducer fill-fluid. This material is a widely available, aromatic phosphate ester with many properties which make it seem a likely candidate. During this quarter we have investigated TCP's potential for long-term corrosion due to hydrolysis. The attack on this question has had two phases. The first was to expose TCP to water for varying times and temperatures, and to monitor hydrolysis from the increase in acidity as determined by potentiometric titration. Because of the very low concentrations of acid produced and the experimental scatter the activation energy of the hydrolysis reaction could not be determined, but this, in itself, was an indication of long-term stability. In a second test, several different metals were exposed to a TCP-H₂O mixture at 60°C, and corrosion was monitored visually as well as by weight change. The metals tested initially were stainless steel, mild steel, aluminum, copper, and brass. A second batch of materials included silver, tin, nickel, and lead-zirconate-titanate type 1 ceramic. The initial group of materials have now been exposed for more than 2000 hours and the second group for 350 hours. Although the temperature acceleration factor cannot be calculated because of the failure of the titration experiment described above, a conservative estimation of the activation energy suggests that the 2000-hour test is equivalent to eight years of 15°C exposure. In this test, none of the material samples has shown any change in weight except the mild steel. The attack on this material is in the form of pitting corrosion. This test is now being repeated, but indications are that hydrolysis of TCP would not be a problem in transducers.

A compatibility series between TCP and transducer elastomers has been conducted. From this test, TCP is seen to have excellent or good compatibility with Viton, butyl, chlorobutyl, silicone, and EPDM elastomers. TCP shows marginal compatibility with natural rubber and poor compatibility with neoprene, nitrile, and polyurethane elastomers. A second compatibility series is underway with other transducer materials which includes a cork-rubber composite, polycarbonate, and an epoxy adhesive.

Multiple determinations of the electrical resistivity of TCP have given the unexpected result that this property does not depend strongly on the water content - as it does with other fluids. The volume resistivity has had a typical value of 2×10^{10} ohm-cm. This value is marginal for some applications, but may well be considerably higher in more carefully refined grades of TCP.

A survey of the manufacturers' literature has shown that TCP presents little hazard in use. When a modern, refined grade is

considered (i.e., where the toxic ortho isomer has been removed) TCP is practically nontoxic orally, is not an eye or skin irritant and is for any practical purpose non-flammable.

2.3.2. An extensive series of compatibility tests are underway with Isopar M. This material is widely used as a towed-array fill-fluid. It is a narrow boiling range petroleum distillate which is marketed by Exxon as a solvent and process fluid. It should have better compatibility with a range of polymers than lower boiling materials such as kerosene. However, tests conducted at USRD indicate several severe incompatibilities. These include butyl, natural, EPDM, silicone and carboxy-terminated butadiene-nitrile elastomers. Neoprene and polyurethane show marginal compatibility while nitrile rubber shows good compatibility. A second series of compatibility measurement has been started. The materials exposed in this test are syntactic foam, cork-neoprene composite, cork-silicone composite, epoxy adhesive, polycarbonate plastic, and Tygon-brand tubing.

2.4. PLANS

- Continue work on water permeation into sonar transducers and the effect this has on operation and lifetime (cooperative between Tasks A-1 and F-1).
- Complete current phase of research on TCP as a transducer fluid (Apr 1980).
- Perform testing on modified PTMG fluid (May 1980).
- Publish report containing detailed physical, chemical, and acoustic properties of a wide variety of transducer and towed-array fluids.

3. TASK B-1 - CORONA ABATEMENT

L.P. Browder - NRL-USRD

3.1. BACKGROUND

A significant percentage of transducer failures is due to voltage breakdown of insulating materials developing from corona erosion mechanisms. It is not practical to test the end item (transducer) to quantify the effects of corona erosion on transducer reliability and lifetime. Corona must be studied as a failure mechanism at the component or piece-part level to quantify the protection requirements and establish reliability factors. Transducer reliability may then be achieved by control of design parameters and construction processes.

3.2. OBJECTIVES

The objectives of this task for FY80 are:

- A complete investigation of the lifetime function of PZT ceramic exposed to various levels of corona discharges in different gases and gas impurity mixtures.
- A formulation of the elementary transducer reliability function based on electrical breakdown considerations.

3.3. PROGRESS

The PZT ceramic lifetime function for the continuous application of 60 Hz voltage was evaluated in air mixed with unusual amounts of carbon dioxide (CO_2), methane (CH_4), or argon (Ar) gases. A description of the test was given in the STRIP FY79 Fourth Quarter Progress Report [2]. Figure 3.1 shows the data for these gas mixtures compared to the normal results for dry air [2].

Argon (Ar) is one of the noble gases that appears in group VIIIA of the periodic table. It is naturally present in air with a concentration ratio of approximately 1%. The noble gases are electrically weaker than air [3] and therefore the effect of this gas component on the voltage lifetime function of PZT ceramic in air deserves evaluation. For this purpose, the gas mixture of 25% argon with 75% air was used. Figure 3.1 shows that the short-term withstand capability of this mixture was decreased about 4%, but the intermediate region was substantially increased above that of air. The argon appeared to interfere with the action of another gas component in air, probably oxygen, to produce this effect.

Methane gas (CH_4) is sometimes present in air as a contaminant. It can also be introduced into a closed electrical insulation environment as a breakdown product of organic insulation materials when acted on by electrical discharges. If the concentration fraction of methane in air is in the range 5-15%, the mixture is explosive. Therefore, only a low concentration of methane was of interest, and in this study a value of 3% was used. The lifetime function shown in Fig. 3.1 for this gas mixture indicates that the methane improves the voltage endurance of the PZT ceramic, however, a negative effect observed was that the methane mixture allowed corona discharges to form that were nearly ten times greater than with air alone.

Carbon dioxide (CO_2) is present in air with a concentration ratio of approximately 0.033%. This is somewhat variable with environment and in order to establish a definite trend in these tests, a concentration ratio of 25% for CO_2 was used. Figure 3.1 shows that this gas mixture compared to air had a voltage withstand capability of 10-17% greater. There was also some indication that the intensity of corona activity was reduced in the CO_2 mixture. Although carbon dioxide is a stronger insulator gas than air, it is not recommended for use in sonar transducers because it permeates very readily through elastomer boots.

The results of these tests indicate that none of these three gas components of air have a significant negative effect on the voltage lifetime function of PZT ceramic. The nitrogen and oxygen components probably dominate the makeup of the function with oxygen contributing both to the strength of the short-term voltage withstand capability and the relative weakness in the long-term area.

A significant feature of the CO_2 mixture curve is that the intermediate region almost exactly repeats the curve obtained using pure perfluoroethane (C_2F_6) gas [1]. There is also a fair similarity to the curves obtained with sulfur hexafluoride (SF_6) and perfluoropropane (C_3F_8). There appears to be a fundamental failure mechanism associated with the PZT ceramic surface that forces the lifetime function to follow this basic curve independent of the maximum strength of the gas. Of course there is also a minimum strength requirement for the gas.

3.4. PLANS

3.4.1. Tests will be conducted to evaluate the effect of temperature on the PZT ceramic lifetime function and corona inception levels.

3.4.2. Continue the investigation of the parasitic current phenomena that leads to electrical failure of PZT ceramic.

3.4.3. Study the instrumentation requirements for investigating the drive frequency effects on electrical breakdown of PZT ceramic.

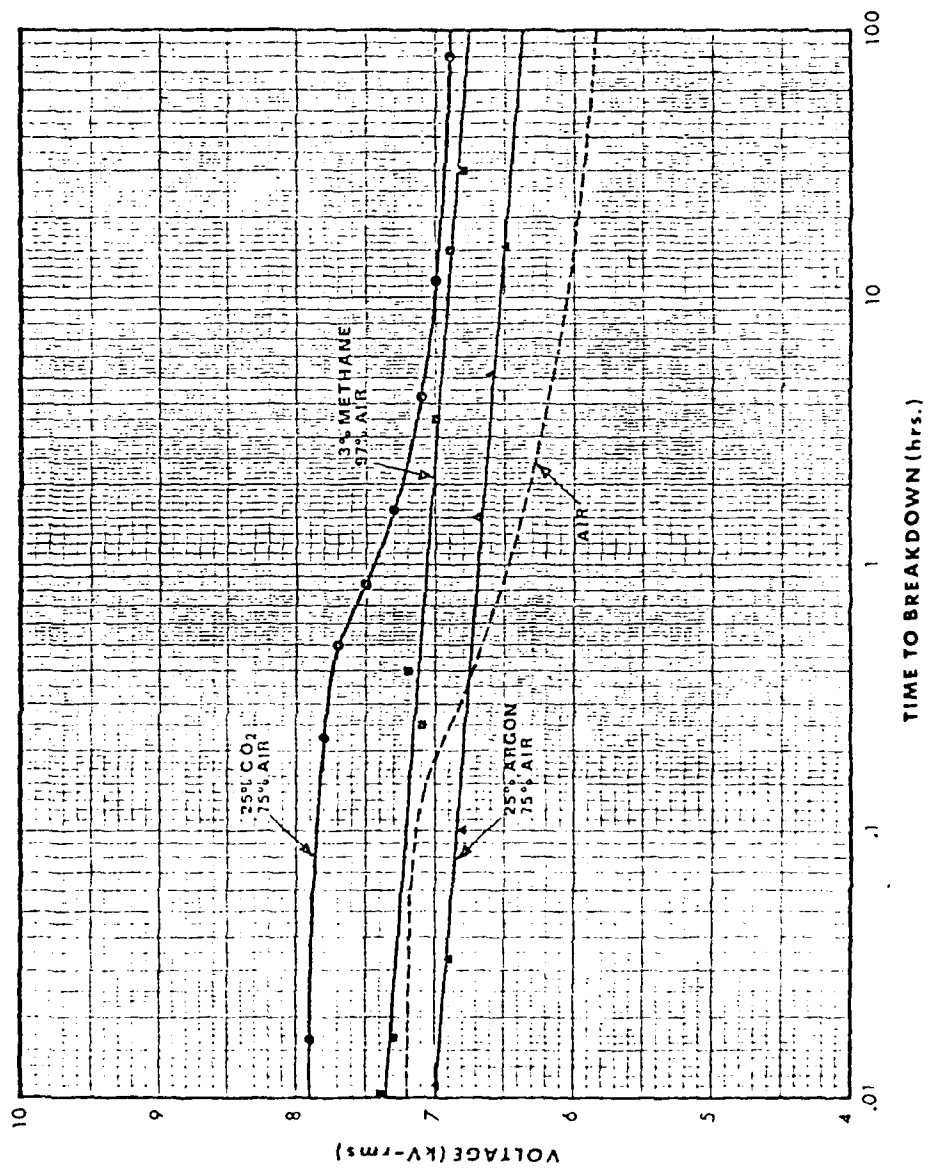


Fig. 3.1 - Voltage lifetime functions for 0.635-cm thickness PZT ceramic in air and mixtures with the gases Ar, CH₄, and CO₂.

4. TASK C-1 - HANDBOOK FOR CONNECTOR AND CABLE HARNESS DESIGN

G.D. Hugus - NRL-USRD

*R.F. Haworth - General Dynamics Corp.,
Electric Boat Division*

4.1. BACKGROUND

The selection of pressure-proof connectors and cable harnesses for hydrophones and transducers is a critical part of Navy shipboard sonar system design. Yet, the design of these components for use in this environment is not covered in any one reference publication. Information on this subject is contained in a multitude of military and industry specifications, standards, and publications. The result is that engineers and designers often duplicate work and may overlook relevant information that they need.

4.2. OBJECTIVE

The objective of this task is the preparation of a design handbook covering the technology of pressure-proof underwater connectors and cable harnesses for hydrophones and transducers. The emphasis will be on the application of these components for use in Naval surface ships and submarines.

4.3. PROGRESS

Work to fulfill this objective began on 31 January 1980 under contract N61339-80-C-0021 by the Electric Boat Division of General Dynamics Corporation. The following is the handbook's approved table of contents together with a brief explanation of each section.

- Responsible NAVSEA Technical Agencies

NAVSEA Technical Codes responsible for sonar transducer and hydrophone design, pressure-proof connector design and outboard cable design will be listed.

- NAVSEA-Approved Pressure-Proof Electrical Connectors

NAVSEA-approved pressure-proof electrical connectors suitable for use on surface ship and submarine sonar systems will be identified; appropriate specifications and drawings will be listed; available connector types and sizes will be noted; full-scale connector assembly drawings will be provided; and connector component parts will be identified. Specifications will include MIL-C-24231, MIL-C-24217, MIL-C-22539, CPG 1027, DSV, and miniature.

- NAVSEA-Approved Outboard Cables

NAVSEA-approved outboard cables suitable for use on surface ship and submarine sonar systems will be identified; appropriate specifications will be listed; a table will note available cable types and sizes; and cable constructions will be identified.

- NAVSEA-Approved Cable Harnesses

Cable harness designs which have been approved for use on sonar systems by NAVSEA will be identified.

- Preferred NAVSEA Pressure-Proof Connectors and Harnesses for Submarine Sonar Systems

NAVSEA-preferred pressure-proof connector and harness designs for submarines will be identified. Recommended connectors, cables, and harness termination methods will be listed.

- Pressure-Proof Electrical Connector Design

The parameters involved in the design of pressure-proof electrical connectors will be listed. Figures will be provided showing all of the various connector design elements which must be considered. Reasons will be given for considering these connector design elements.

- Connector Receptacle Attachment Methods

Various methods for mounting and sealing connector receptacle to hydrophone and transducer enclosures will be listed. Figures will be provided detailing attachment and sealing methods. Recommendations will be provided for preferred methods of attachment and sealing. Receptacle welding procedures will be provided, as applicable.

- Outboard Cable Design

The parameters important in the design of outboard submarine sonar cables will be listed. Recommendations will be made for conductor, conductor insulation cable fillers, binders, braided shielding, and cable jacketing materials suitable for outboard cables.

- Cable Harness Design

Various types of cable harness designs such as jacketed cables, oil-filled cables, and mineral-insulated cables

will be described; and the advantages and limitations of each will be given.

- Connector Termination Methods

Cable to connector termination procedures will be provided for polyurethane, neoprene, butyl and polyethylene molded cable boots. A potted shrink tubing type molding procedure will also be detailed. A connector wiring and molding fabrication procedure checklist will also be provided.

- Cable Splicing - Repair Methods and Procedures

Various acceptable methods of splicing outboard cables will be detailed - such as polyurethane, neoprene, polyethylene and butyl molded. Shrink tubing and other methods will also be covered.

- Cable Harness Test Requirements

Recommended procedures for testing harnesses following fabrication and as installed will be provided.

- Cable Harness Handling, Installation, Replacement, and Testing

Procedures for handling, installation, replacement and testing cable harnesses following installation will be detailed. An installation check-off list will be provided.

- Quality Control Considerations

Quality control considerations for pressure-proof cable harnesses will be discussed. An FMEA for a typical submarine outboard cable harness will be prepared.

- Typical Failure Modes and Effects Analysis (FMEA) for Connectors and Cable Harnesses

An FMEA will be provided for a typical pressure-proof connector and cable harness.

- References

Pertinent available references on outboard cables, connectors and harnesses will be listed such as military specifications, handbooks, design studies and test programs.

- Bibliography

A bibliography will be provided on the subject.

- Appendix A - Glossary

A glossary will be provided on outboard cables, connectors, and harnesses which is generally agreed upon by the industry.

- Appendix B - Tables

Pertinent tables useful in undersea cable and connector design will be provided

- Appendix C - PP Connector, Cable and Harness Supplier Listing

A listing of approved suppliers of the subject cable, connector and harness will be provided.

- Appendix D - Listing of U.S. Personnel Involved in PP Connector and Harness Design and Use

The listing will provide names, places of business, and phone numbers.

A first draft of the entire handbook is being prepared, it will be submitted for NAVSEA approval, and the approved version will be published by the Navy.

Engineering literature is being accumulated for the technical sections, and the first draft of the appendices and bibliography is complete. Presentations were given at the STRIP FY80 Annual Review and at the Marine Technology Society Undersea Cable and Connector Committee Workshop appealing for pertinent inputs to the handbook.

4.4. PLANS

The third quarter of FY80 will be devoted to completing the first draft of the first seven sections shown in the table of contents. Work during the remainder of FY80 will be carried out in preparing the rest of the first draft of the handbook.

5. TASK C-2 - STANDARD FOR O-RING INSTALLATION

Dr. Colin J. Sandwith - APL, University of Washington
G.D. Hugus - NRL-USRD

5.1. BACKGROUND

The reliability of sonar transducer arrays can be significantly improved by the adoption of standard procedures for the installation and assembly of O-ring seals. The problem is that no such standard procedure exists. Presently, the installation procedures are determined by the installer and the materials available at the time of installation.

The results of analyzing failures of O-ring seals in connectors used in underwater applications over decades show that roughly eight out of thirteen O-ring failures have resulted from improper installation and assembly or improper quality control and inspection procedures at the time of assembly. Stated another way, the results showed that even though O-ring seal design may be perfected by the proper O-ring type selection (piston, face, or crush) by the maximum crush section thickness, by selecting the proper O-ring size and material, and by using two O-rings in series (double O-rings) a substantial number of the O-ring seal failures will occur due to improper installation and inspection procedures.

5.2. OBJECTIVES

The objective is to compose, critique (by authorities), edit and present in final form a standard procedure for the installation of O-ring seals in electrical connectors and undersea static application. The standard will be composed in the form of similar military standards. Once the standard is approved by NRL and NAVSEA authorities it will be submitted for approval as a military standard.

5.3. PROGRESS

Work to fulfill this objective is being performed under contract N00024-78-C-6018 by the Applied Physics Laboratory of the University of Washington. The approach to developing this procedure is to use all known proven techniques and procedures of users (military and commercial) and suppliers to develop a unified best procedure. The approach is to collect from the literature, users, and suppliers, all of the data and recommendations concerning each phase of the O-ring seal production.

The tentative table of contents and a listing of standards and instructions to be included in the standard procedure is as follows:

Forward
 List of Tables
 List of Figures
 Definition and Description of Terms
 Acquisition and Procurement
 MIL-P-5514; MIL-P-5516; MIL-P-25732
 Packaging
 MIL-O-4861A; MIL-HDBK-695; MIL-STD-726F
 Individual Package, Polyethylene Lined
 Storage and Aging
 MIL-P-5516; MIL-HDBK-695A
 Parker HDBK ORD-5700 pp A3-13, A3-15
 T<120°F
 Exclude O₂, Contaminates, Light, Ozone, Radiation
 Installation
 MIL-G-5514F (Design responsibilities)
 Parker O-Ring Guide for Industrial Maintenance Men,
 Copyright 1975
 Parker O-Ring Guide for Aircraft Maintenance Men,
 Copy right 1968
 NAVSHIPS-0280-651-5000 (formerly NAVSHIPS 93793)
 Cleaning, Inspection, Lubricating, Placement,
 Extraction, Coupling, Tool Use and Case
 Tools
 Parker O-Ring Guide for Industrial Maintenance Men,
 Copyright 1975, pp 12, 13
 Inspection and Test
 MIL-STD-413; MIL-STD-177
 Parker O-Ring HDBK ORD-5700 A5-1
 Reliability
 Accountability Procedures
 Redundancy
 Responsibility
 Instructions and Illustrations
 Lubricants
 MIL-L-4343B; MIL-L-17192C (Navy)
 Parker O-Ring HDBK ORD-5700, A4-3, A4-4
 (do not use MIL-G-3278A)
 Lubricant Thickness and Distribution
 O-Ring Problems and Their Causes
 Secondary Seal for Symbol 713 (Portsmouth) Submarine
 Connectors
 "Performance/Failure Analysis---" by Sandwith, MTS-IEEE
 Oceans, 1978, pp 273-286
 "Reference Manual on Interference Seals and Connectors
 for Undersea Electrical Applications," NTIS ADA 036841
 Parker O-Ring HDBKs
 Applicable Documents and Other Publications

Appendix

Types of O-Ring Seals

Engineering

MIL-HDBK-692(MR)

MIL-HDBK-149A

Squeeze

Squeeze and Roughness Relationship

MIL-P-25732B

MIL-C-24231/11C (SHIPS)

The following authoritative individuals have been chosen to review the first draft of the O-ring standard which is nearly complete.

R.F. Haworth, Group Leader, Engineering, Electric Boat Division, General Dynamics Corporation

A.C. Porterfield (retired) TRF Technical Support, Design Division, Mare Island Naval Shipyard

W. Green, Division Marketing Specialist, O-ring Division, Parker Hannifin Corporation

5.4. PLANS

The first draft will be submitted to the three chosen individuals for review during the third quarter of FY80. After appropriate revision, a draft will be submitted to the STRIP Program Manager for review and recommendations.

Final publication will be during the fourth quarter of FY80.

6. TASK C-3 - CABLES AND CONNECTORS

G.D. Hugus - NRL-USRD

D.E. Glowe - Texas Research Institute

6.1. BACKGROUND

The use of cables and connectors is an area of concern for long-term sonar reliability because of a history of failures. Deficiencies can be generally categorized in the four areas of: design of cables and terminations; specification and testing; handling; and repair and maintenance. Specific problems have been identified in a recent failure modes and effects analysis of cables and connectors prepared for NAVSEA by General Dynamics/Electric Boat. They conclude, that of all the problem areas, the loss of bond of the molded boot to the connector shell or to the cable sheath is the most probable cause of failure. Cable jacket puncture in handling, at installation or in service, is considered to be the second most probable cause of failure.

6.2. OBJECTIVES

The general objective of the task is to provide improved reliability in the cables, connectors, and related hardware for the outboard elements of sonar transducer systems.

Specific objectives for the FY80 task area are to complete the following:

- Investigate the strength of unshielded cable and the shielded cable to determine reliability and failure modes.
- Investigate the use of cable/connector boot clamps to determine reliability and failure modes.

6.3. PROGRESS

6.3.1. Work is continuing under contract N00173-79-C-0129 by Texas Research Institute, Inc.

- Tasks 1 through 3, performed to fulfill the first objective above, are complete and were outlined in the STRIP FY80 First Quarter Progress Report [1].
- Tasks 4 through 8 are being carried out in support of the second objective. Task 4 and 5 are complete and were described in the previous STRIP quarterly report [1].

- Task 6: Conduct Factorial Experiment

Testing is complete under this task and Table 6.1 is a list of the resulting failures. Of the connectors that survived the tests, nine remained above 100 MΩ in test resistance, with only one of these being molded of polyurethane. A water soluble dye penetrant has been obtained for use in visually tracing leakage paths. Procedure for analysis of the failures is:

- a. Application of dye penetrant under hydrostatic pressure.
- b. Bond strength estimations by measuring that tensile force required to pull the cable or backshell from the boot.
- c. Dissection of the boot and obstruction of residual dye under ultraviolet light.

All connectors have been treated with the penetrant and the strength required to separate the connector boot measured.

- Task 7: Conduct Accelerated Life Tests on Connectors

A set of 64 instrumented control connectors manufactured under Task 5 was subjected to accelerated life testing (ALT). The 36 control connectors were molded of polyurethane, bonded to the shielded cable with no clamps. Since initial results of Task 6 indicate that the neoprene boot outperforms polyurethane, the remaining connectors (32) were made with neoprene.

All backshells were clamped with Band-It Jr. PREFORM clamp (¼-in. wide). Sixteen were clamped at the boot/cable interface and sixteen were not.

The final ALT test plan is shown in Table 6.2. After testing began, a failure occurred with the temperature control for the ALT dry heat oven (cycle 3) and all 64 test connectors were exposed to a maximum temperature of 120°C for as much as six hours. Upon pressure cycling, eleven polyurethane and three neoprene connectors failed. The cables on the failed connectors showed separation of the jacket from the shield and this deterioration appears to be the

failures. However, the excessive temperature to which the connectors were exposed casts some doubt on the validity of the results. Therefore, this task will be redone.

- Task 8: Analysis of Test Results

The results of Task 6 are being analyzed and a failure mode analysis is being performed. From Table 6.1 it is seen that the majority of failed connectors were molded of polyurethane and the predominant leakage path was at the cable boot interface.

6.3.2. Preliminary results of STRIP Task C-3 were reported at the Marine Technology Society Cable and Connectors Workshop.

6.4. PLANS

The set of 64 test connectors will be rebuilt and ALT will begin so that Task 7 may be reliably carried out. Test oven temperature safety controls will be added to all heat-aging containers to prevent future temperature control failures. Testing and data analysis will be completed next quarter.

Connector No.	Type	Analysis	Action
2	PU-U DSS-3 No Clamp	Cable bond failure, cycle 3	Removal from test after cycle 4
6	PU-U DSU-3 No Clamp	Cable bond failure during cycle 3	Clamp added to boot over cable
18	PU-U DSU-3 PRE-FORM	Boot cracked under clamp after cycle 7, low cable resistance	Removed from test after cycle 7
10	PU-U DSS-3 OETIKER	Cable bond failure, under gap in clamp	Remove from test after cycle 5
11	N-G DSS-3 OETIKER	"O" ring leakage was not recognized and connector prematurely dissected	Removed from test after cycle 3
14	PU-U DSU-3 OETIKER	Cable bond failure during 4th cycle. Low cable resistance during cycle 2.	Removed from test after 4th cycle
25	PU-G DSS-3 SCRU-LOKT	Cable shorted, apparently mechanically, no leakage noted	Removed after 4th cycle, returned to test after failure analysis
26	PU-U DSS-3 SCRU-LOKT	Cable bond failure	Removed from test after 5th cycle
29	PU-G DSU-3 SCRU-LOKT	Lack of bond on back shell and cable, leakage on both interfaces	Removed from test after 7th cycle
5	PU-G DSU-3 No Clamp	Bond failure on cable after cycle 8	Removed from test after cycle 8
9	PU-G DSS-3 OETIKER	Low resistance on cable during cycle 7. Flooding through cable on cycle 8	Removed from test after cycle 8
22	PU-U DSU-3 Preform	Low cable resistance during cycle 4, flooded at cycle 8	Removed from test after cycle 8
20	N-U DSS-3 Preform	Cable sensor broken at cycle 4, removed from test cycle 7, 8, & 9	Returned to test @ cycle 10
3	N-G DSS-3 No Clamp	Cable resistance continuous at final reading	Complete
4	N-U DSS-3 No Clamp	Cable resistance continuous at final reading	Complete

PU - Polyurethane
N - Neoprene

G - Bonded
U - Unbonded

Table 6.1 - Connector Failure Analysis

Cycle	Time, Hrs.	Temp, °C	Conditions
1	64	70	sea water soak
2	1	-78	dry cold
3	7	70	dry heat*
4	16	70	sea water soak
5A*	8	25	fresh water and pressure cycle
5B*		70	sea water soak
6	16	70	sea water soak
7A*	8	70	sea water soak
7B*		25	fresh water and pressure cycle
8	40	70	sea water soak
9	1	-78	dry cold
10	7	70	dry heat
TOTAL	168		

Repeat cycle.

* Order reversed for one-half of the connectors.

Table 6.2 - Preliminary ALT Test Plan

7. TASK D-1 - ALTERNATIVE MATERIALS: PLASTICS

D.E. Moore - NWS

C.M. Thompson - NRL-USRD

7.1. BACKGROUND

Corrosion, cost and acoustic characteristics are parameters that must be considered when selecting a material for the design of a sonar transducer. In the past decade, plastics have decreased in cost and increased in strength to the point that they are in strong competition with metals for specific applications. Plastics could be used as a design material for sonar transducers in order to lower costs and lengthen service life if they can withstand the ocean environment. An additional advantage is that plastics generally are electrically nonconductive and acoustically transparent.

Specifically, the injection molded thermoplastics are the best materials for consideration as an alternative assembly material since they can be molded to close dimensional tolerances and in many configurations. Metals and electronic connectors can be molded directly into the plastics thus reducing the number of separate parts and insuring in-service reliability.

Naval facilities equipped with the proper molding equipment can fabricate replacement parts for sonar transducers when parts are not in stock or readily available. This would be extremely helpful when emergency repair is necessary and the time for normal procurement procedures is not available. In the event that a shortage of material should occur, thermoplastics can be easily recycled.

Presently, there are no general long-term ocean immersion data available for thermoplastics. It would take many years of testing and analysis to determine the long-term life expectancy, but there is an immediate need for information. The only approach for determining this information in a reduced time period is to perform accelerated life testing, but this must be done with caution. When this method is used, it is always recommended that comparison be made to parts which have been exposed to the actual environment in question.

7.2. OBJECTIVE

Evaluate the ability of plastics to withstand an ocean environment and the reliability of the accelerated life test method for use in determining long-term material life expectancy.

7.3. PROGRESS

The approach to this project is as follows:

- Perform a two-year equivalent accelerated life test (ALT) on eight types of glass-filled thermoplastic materials immersed continuously in substitute ocean water (ASTM D-1141)
- Immerse eight types of thermoplastics in an ocean environment, with an approximate constant temperature for two years.
- Evaluate test specimens of both aging environment for changes in major material properties.
- Compare the data for the two environments to determine both the aging characteristics and the validity of a 10-20 year equivalent accelerated life test for glass-filled thermoplastics.

A meeting was held with Dr. C.M. Thompson at the Naval Research Laboratory (NRL) in Orlando to establish a testing procedure for this project and to select the type of plastic materials to be evaluated. The materials that were selected are:

Polycarbonate, 40% Glass-filled
Polysulfone, 30% Glass-filled
Polyphenylene Sulfide, 40% Glass-filled
Nylon 6/10, 40% Glass-filled
High Strength Nylon (Zytel), 40% Glass-filled
Amorphous Nylon, 40% Glass-filled
PBT Polyester, 40% Glass-filled
Polyphenylene Oxide/Styrene (Noryl), 30% Glass-filled

At the March 1980 annual review, the question was asked if the glass used in these plastic materials were silanized. Silane may be thought of in much the same way as a "sizing agent." These materials are added to the glass to activate the surface before adding to the plastic. This increases the bond strength between the plastic and the glass fiber, and will retard the degradation of the bond by water. Some of the plastics in this study use silanized glass while the remainder use other sizing agents.

The test specimens will be removed at varying intervals for both aging environments. Each time, material property tests will be

performed for:

Tensile Strength (ASTM D-638)
Shear Strength (ASTM D-732)
Water Absorption (direct measurement: ΔW)
Volumetric Change (direct measurement: ΔV)
Sound Speed (time-of-flight velocimeter)

If the results of degradation for the ocean test support the laboratory accelerated test, it will be possible to accurately determine the extended life expectancy of plastics.

Recently, recommendations were made for evaluating additional parameters of creep and degradation when fatigued or stressed. These are important considerations, but time and funds make it impossible to perform this analysis for this project time frame (FY80). In the event that this task is continued, these topics will be investigated.

One property evaluation that will be performed in addition to the existing procedure is the effect of seawater on machined plastics. This will be accomplished by milling the surfaces of molded test specimens of selected materials. The parts will be evaluated according to the aforementioned procedure, but tested at lesser intervals. This will provide some indication if machining does drastically effect strength and the resistance to moisture absorption.

Test specimens are still being molded and the expected completion date is in May 1980. At that time, the parts will be installed at the ocean site and the accelerated life procedure will be initiated.

7.4. PLANS

- Complete test specimen fabrication
- Test plastics for baseline data
- Install parts at ocean test site
- Begin accelerated life test
- Perform parts evaluation
- Compile data and present results

8. TASK D-2 - MATERIALS EVALUATION

C. LeBlanc - NUSC

C.M. Thompson - NRL-USRD

8.1. BACKGROUND

Pressure release materials are used to mechanically and/or acoustically isolate some components of sonar transducers to improve overall acoustic performance. Normally the pressure release materials must operate effectively under bias stress anywhere from 0.3 MPa (50 psi) to 20 MPa (3 kpsi) over a discrete temperature range, e.g., 5 to 40°C. To predict performance it is essential to know the properties of the materials under the imposed constraints. Previous measurement methods for determining the properties of some pressure release materials, such as Sonite (an asbestos - glass fiber composite), onion-skin paper, syntactic foams, Hytrel (a thermoplastic polyester elastomer), etc., have given relative results with a hydraulic press or bulk effects with an impedance tube. There is a strong need to correlate existing measurement data and to establish a standard measurement system to be used by the Navy for incorporation into specifications and/or acceptance tests on pressure release materials.

An additional problem is that pressure release materials absorb the transducer fill-fluids. This process increases the acoustic impedance of the pressure release material and thus reduces the effectiveness of its acoustic insulation. Degradations of from 3 dB in 3 years to 6 dB in 10 years have been reported in transducers in the field, and attributed to changes in the pressure-release material.

There are thus two phases to this task: the material characterization phase and the fluid absorption phase.

8.2. OBJECTIVES

The objectives of this task are:

- To initiate and evaluate a standard static and dynamic measurement system to determine the properties of pressure release materials over the ranges of stress from 50 psi to 3 kpsi and at temperatures from 5 to 40°C.
- To measure and evaluate candidate pressure release materials, such as Sonite, onion-skin, corprene, etc.

- To quantify the changes in acoustic properties of cork-rubber composites as they absorb transducer fill-fluids.
- To test a transducer element for changes in sensitivity as a function of castor oil content of its pressure release material.
- To develop a method that will predict changes in the acoustic properties of cork-rubber composites with time (and, in turn, predict changes in transducer directivity and sensitivity).
- To identify the specific problems with DC-100 which may eventually lead to its replacement with a more suitable material.

8.3. PROGRESS

8.3.1. The last four objectives above have now been accomplished and have been reported in previous STRIP reports. A comprehensive final report is being edited and an abbreviated version is being prepared for submission to the open literature.

8.3.2. The math modeling for the dynamic measurement system, described in a previous quarterly progress report, is currently being implemented for use on a medium-sized Hewlett Packard computer, model 9825A, to avoid extensive and expensive computer time in analyzing measurement data. Dimensional information on the driver unit, necessary as input to the computer program, has been acquired and is being relayed to Raytheon for a trial run of the math modeling capability.

The static measurement system, developed to augment the dynamic measurement system to insure correlation of static and dynamic data, disclosed some basic information covering problems with stress related data on elastomeric materials. Previously reported results on paraffin samples, initially thought of as control materials for determining lateral constraint effects on highly compliant materials, showed extensive creep in the material with no apparent recover — at least to the stress levels used. Figure 8.1 shows data taken for two stress cycles on a virgin paraffin sample. The vertical axis is strain in the stress rod, proportional to stress in the sample, T_s . The effect of creep is obvious but the plots indicate that the effects are reduced with cycling (probably because the material is continually being forced into a gradual permanent set). It is necessary to know the number of cycles needed to reduce the effects to a predictable level before any dynamic data can be considered useful.

As another example, a virgin sample of Hytrel, a thermoplastic polyester elastomer contemplated for use in the TR-155 transducer design, was measured and the static data appears in Fig. 8.2. Again it is obvious that stress cycling of the material has a dramatic effect. Even more noticeable is the initial "knee" of the stress (T_s) versus strain (S_s) curve on the first cycle (continued cycling might produce a linear relationship but this aspect must be investigated). If the small-signal dynamic elastic properties of these types of materials can be approximated from the slope of the static curve, whereas the static values themselves are determined from the origin to the stress level of interest, then it is obvious that the static and dynamic values can be substantially different depending on the initial stress conditions imposed on the materials.

Loading of the samples was accomplished by application of a torque to a stress rod. This technique was originally used so that stressed samples could be immediately tested (dynamically) in the detachable sample holder. However, since static stress cycling is required prior to dynamic measurements, the cycling can be achieved easier with a hydraulic press.

It was initially thought that material density variations with stress level could be measured on the same samples which were to undergo dynamic measurements. This scheme proved ineffective since the inside radius of the sample could not be easily measured under stress. Separate small solid samples will be measured for density versus stress behavior.

Because of problems described in this reporting period, the plans for FY80 have been altered to address a specific scheme for at least one pressure release material. Other materials will be measured where feasible.

8.4. PLANS

- Samples will be stress-cycled with a hydraulic press to see if a stability, or lack or creep, can be obtained.
- Measure static and dynamic properties of pressure-release material at ambient temperature.
- Collect information and prepare report on the measurement of properties of pressure-release materials.

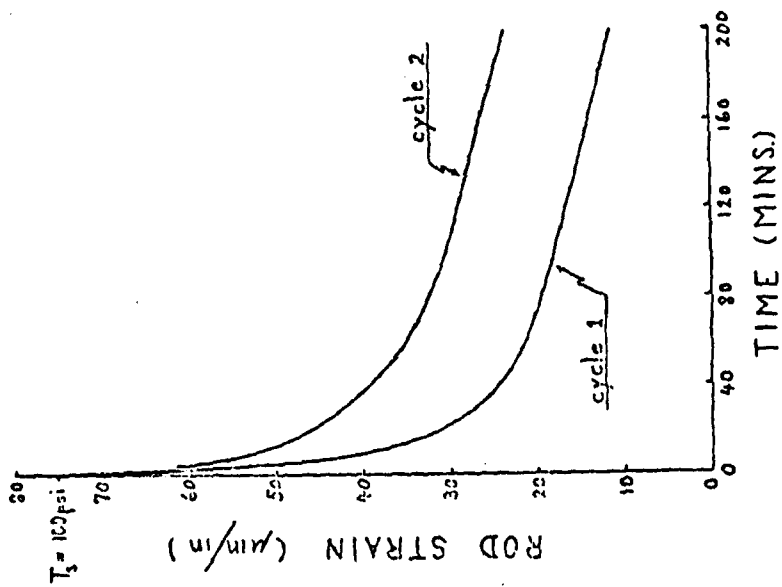


Fig. 8.1 - Relaxation of stress rod with soft sample

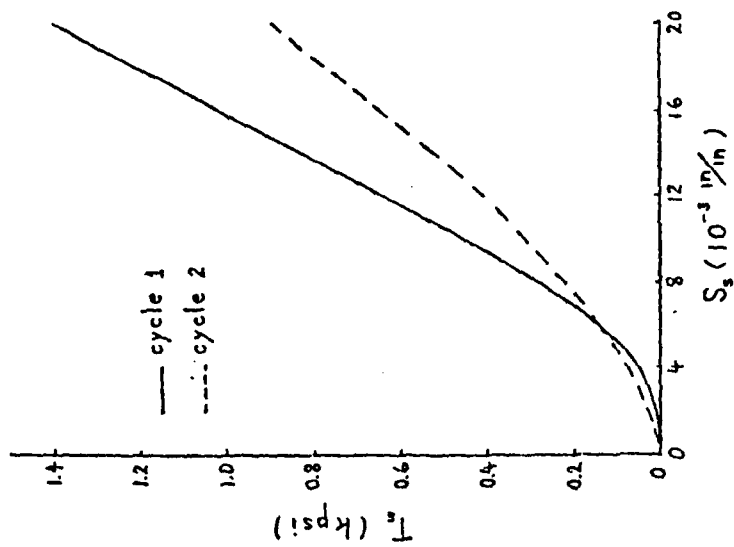


Fig. 8.2 - Hytrel 5556 (virgin sample)

9. TASK E-1 - STANDARDIZED TEST PROCEDURES

J. Wong - NOSC

D. Huckle - NOSC

9.1. BACKGROUND

It is at present not possible to subject a transducer specimen to a series of environmental stresses over a short time period and prove, if it passes certain operating parameter tests, that the specimen is a reliable transducer with a certain minimum expected life in fleet use. Of course, if we could simply use a set of transducers for the desired fleet life, we could check the failure rates against acceptable replacement or repair rates. But the approach here is to accelerate the environmental stress actions, and thereby subject the transducer specimen to seven years of life cycle stresses in a few weeks or months.

9.2. OBJECTIVES

The objective of this task is to develop a set of standardized procedures based upon environmental stress requirements to accelerate the aging of transducers.

9.3. PROGRESS

9.3.1. DT-605 First Article Hydrophones

The second year-equivalent stress exposures under the Composite Unit Accelerated Life Test (CUALT) plan for the two Hazeltine Corporation DT-605 hydrophones (first article, serial nos. A1 and A5) was completed in March 1980. These two hydrophones were formerly identified as DT-308, serial nos. A1 and A5. Table 9.1 shows the CUALT procedures for one year-equivalent of stress for both the DT-605 hydrophone and the TR-316 projector. Acoustic (receive sensitivities, input impedance magnitudes and vertical beam patterns) and insulation DC resistance measurements indicated that no significant deterioration in the performance of the two hydrophones after the second year-equivalent of CUALT.

Prior to the initiation of the CUALT plan, the A1 hydrophone receive sensitivities were measured with the cable outputs open-circuited, not terminated with 50-ohms resistance as required in the Critical Item Procurement Specification (CIPS) dated 10 June 1977. Therefore, no base line receive sensitivities were reported in the STRIP FY80 First Quarter Progress Report [1] for this hydrophone. However, after the 75°C dry heat exposure during the first year of CUALT (Table 9.1) receive sensitivities for both open-circuited and 50-ohms termination conditions were measured for the A1 hydrophone. Comparisons of these

latter measurements with the open-circuited measurements prior to the start of CUALT allow the base line receive sensitivities for the 50-ohms termination condition to be deduced.

Figure 9.1a and 9.1b show the receive sensitivities of the two narrow-beam and the two wide-beam staves, respectively, for the A1 hydrophone. These figures compared the base line receive sensitivities before the start of CUALT with those measured after the completion of the first and second year-equivalent of CUALT. Each of the four beam staves output was terminated with a 50-ohm resistor at the end of a 100-ft 2SWF4 test cable as required in the CIPS. The two narrow-beam staves as well as the two wide-beam staves are still within the specification of ± 1.5 dB at the center-band frequency F_0 and the total variations in sensitivity not more than 4 dB across the operating frequency band of $F_0 \pm 5$ kHz. Note that the measured receive sensitivities at the end of the second year-equivalent are generally lower than the base line and the first year-equivalent values. Because of the measurement error of approximately ± 0.5 dB this may not be indicative of a gradual degradation caused by the two year-equivalent of stress exposures.

The results of the receive sensitivities for the A5 hydrophone are shown in Figs. 9.2a and 9.2b. Both staves in the narrow and wide-beam sections are still within specification as described for the A1 hydrophone. Similarly, the sensitivities at the end of the second year-equivalent are in general lower than the base line and the first year-equivalent values.

The third year CUALT on the two DT-605 units was initiated on 12 March 1980.

9.3.2. New TR-316 First Article Projector

Three new TR-316 first article projectors (serial nos. A1, A2, and A3) were fabricated by Ametek/Straza incorporating the modifications recommended after the extensive tests in uncovering the current-runaway problem during the high-drive test on the prototype TR-316 projectors. These tests and modifications were reported in STRIP FY79 Fourth Quarter Progress Report [2]. The major modifications may be briefly reiterated:

- Revised the resonator-assembly procedures to improve cement joints with lower losses by using a higher prestress on the ceramic stack while the cement cured.

- Replaced the micarta resonator retainer blocks in the wide-beam sections with aluminum resonator retainer blocks to improve the thermal dissipation from the resonators to the projector housing.
- Fill-fluid slot in the tail washer enlarged to provide improved oil filling within each resonator cavity.
- Modified the projector housing to incorporate two fill ports for each of the three beam section cavities as well as modified the oil-fill procedure to incorporate the technique of circulating warm, evacuated oil.

Straza had exposed these three units to 168 hours (7 days) of high drive with frequency sweep at 126 V rms input in approximately 3 m (10 ft) of water during November 1979.

These three projectors were released to NOSC in November 1979. Low-level base line acoustic performance were measured at TRANSDEC in December 1979 and January 1980 and found to be within specifications. It was decided to perform a short duration (approximately one hour) high-drive test on the wide-beam sections of these units prior to submitting them to the CUALT plan. To facilitate impedance monitoring, a single frequency (at the lowest operating band) at 126 V rms was used. A projector was lowered to a depth of 10.5 m (34 ft) the maximum depth at TRANSDEC. The measured impedance magnitudes of the wide-beam sections of the first projector (A3) tested had values approximately 30 ohms lower than that of the low-drive level. It was conjectured that cavitations may be present to alter the projector input impedance. To avoid cavitation, the above test was repeated with the projector inserted in a pressure vessel with a pressure of approximately 483 kPa (70 psi). The impedance magnitude measured when the projector was in the pressure vessel agrees closer to the values at low drive. Although in-depth analyses of the test data have not been completed at this time, it may indicate that proper water depth is necessary for the high-drive tests to avoid the potential damaging effects of cavitation.

Two of the three TR-316 projectors will be initiated into the CUALT plan shortly.

9.3.3. Impact of TR-316 CUALT on TR-242 Projectors

The TR-242 projectors which are currently used in the under-ice sonar system (AN/BQS-15) have identical resonators as in the TR-316 projectors. There is only one narrow-beam and one wide-beam in each TR-242 projector.

The cement joints problem in the TR-316 resonators, uncovered by the in-air impedance versus temperature tests, led to the following specific changes in the assembly procedure for the TR-242 resonator ceramic stack:

- Assembly procedure change for the resonator (Drawing EO Serial No. 56837)
- Nodal ring design change (Drawing EO Serial No. 55884)
- Resonator assembly pictorial (Drawing EO Serial No. 56834)
- Tail assembly change (torquing requirement) (Drawing EO Serial No. 55885)

9.3.4. CUALT Report

A report entitled "Composite Unit Accelerated Life Testing (CUALT) for Sonar Transducers - Part 1," TR-316, covering work on the CUALT task up to the end of FY79 is expected to be published by NOSC in May 1980.

9.4. PLANS

- Continue with CUALT on the two Hazeltine Corporation DT-605 hydrophones to complete as many as possible of the seven year-equivalent CUALT.
- Initiate CUALT on the new Ametek/Straza TR-316 projectors and complete as many as possible of the seven year-equivalent CUALT.
- Make necessary revision of CUALT plan to improve speed and cost-effectiveness of more year-equivalents of TR-316 and DT-605 stress exposures.
- Start development of CUALT procedure for the SQS-56 transducers.

Table 9.1 Composite Unit Accelerated Life Test (QUALT) Simulating One Equivalent Year of Stress for IR-316 () or DT-605* (Revised July 78)

Exposure	Time	Purpose	Time Compression	Equivalent Service
1 Dry Heat 75° C UV Exposure*	475 Hours	Accelerate rubber degradation, reaction between fill fluid & components, mechanical stress on boot due to expansion, degradation of rubber, simulate dockside storage. TEST: 40 hrs BEAM PATTERN, TVR, OIL PRESSURE, RUBBER CHANGES, MEGGER	Accelerated aging Duty Cycle increase	16,300 hrs at 70°F (E = 3100 J/mole) 1-2 hrs/day of sunlight for 9 mo.
2 Fresh Water 60°C*	TEST: 40 hrs TEST: 250 cycles	Water permeation, simulate wet operation MEGGER	Accelerated Aging	575 hrs at 20°C (E=3100 J/mole) 18,750 hrs at 20°C (E = 7170 J/mole) 1 year diving
3 Pressure Cycling	2 X 16 hrs	Mechanical stress, water intrusion, water permeation, simulate diving conditions MEGGER, ACOUSTIC PROBE	Duty cycle increase	32 hrs at Pressure
4 Thermal Shock -54° to 0°C	3 cycles	Mechanical stress due to contraction elastomer and adhesive integrity, water intrusion, simulate, arctic conditions.	Duty Cycle increase	One Arctic mission
5 Repeat Pressure Cycling & Dwell	Same as Exposure No. 3 TEST: BEAM PATTERNS, TVR, IMPEDANCE			
6 High Power Drive *	168 hrs	Simulate continuous operation	Duty Cycle increase, stress increase	One Arctic mission

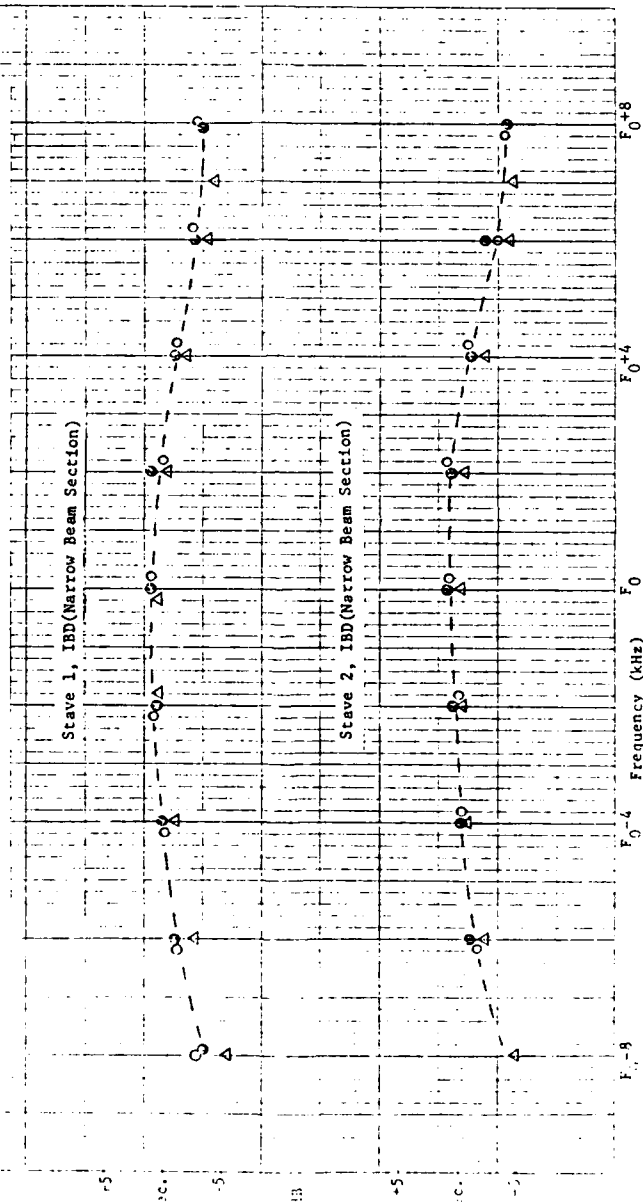
*UV, Fresh Water 60°C and High Power Drive exposures are eliminated for the DT-605 hydrophone.

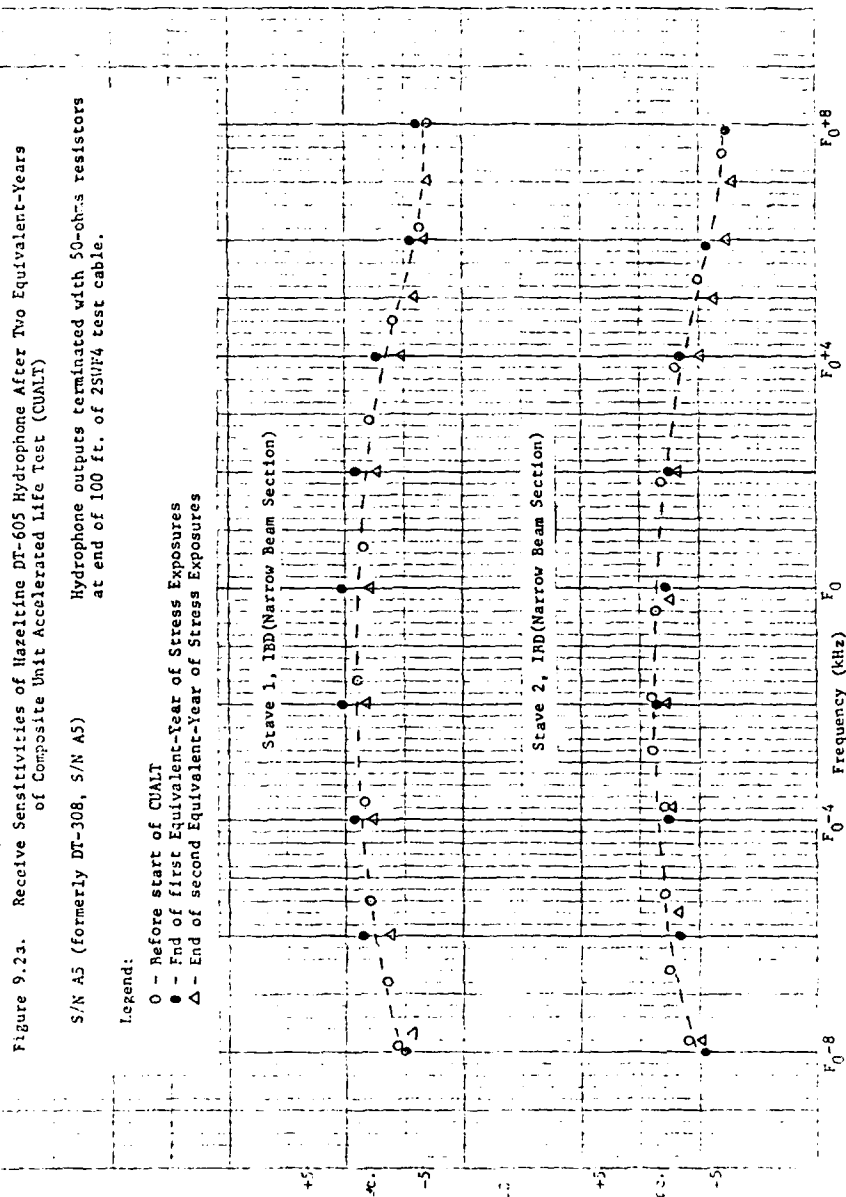
Figure 9.13. Receive Sensitivities of Hazeltine DT-605 Hydrophone After Two Equivalent-Years of Composite Unit Accelerated Life Test (QUALT)

S/N A1 (formerly DT-308, S/N A1) Hydrophone outputs terminated with 50-ohms resistors at end of 100 ft. of 25NF4 test cable.

Legend:

- - Before start of QUALT
- - End of first Equivalent-Year of Stress Exposures
- △ - End of second Equivalent-Year of Stress Exposures





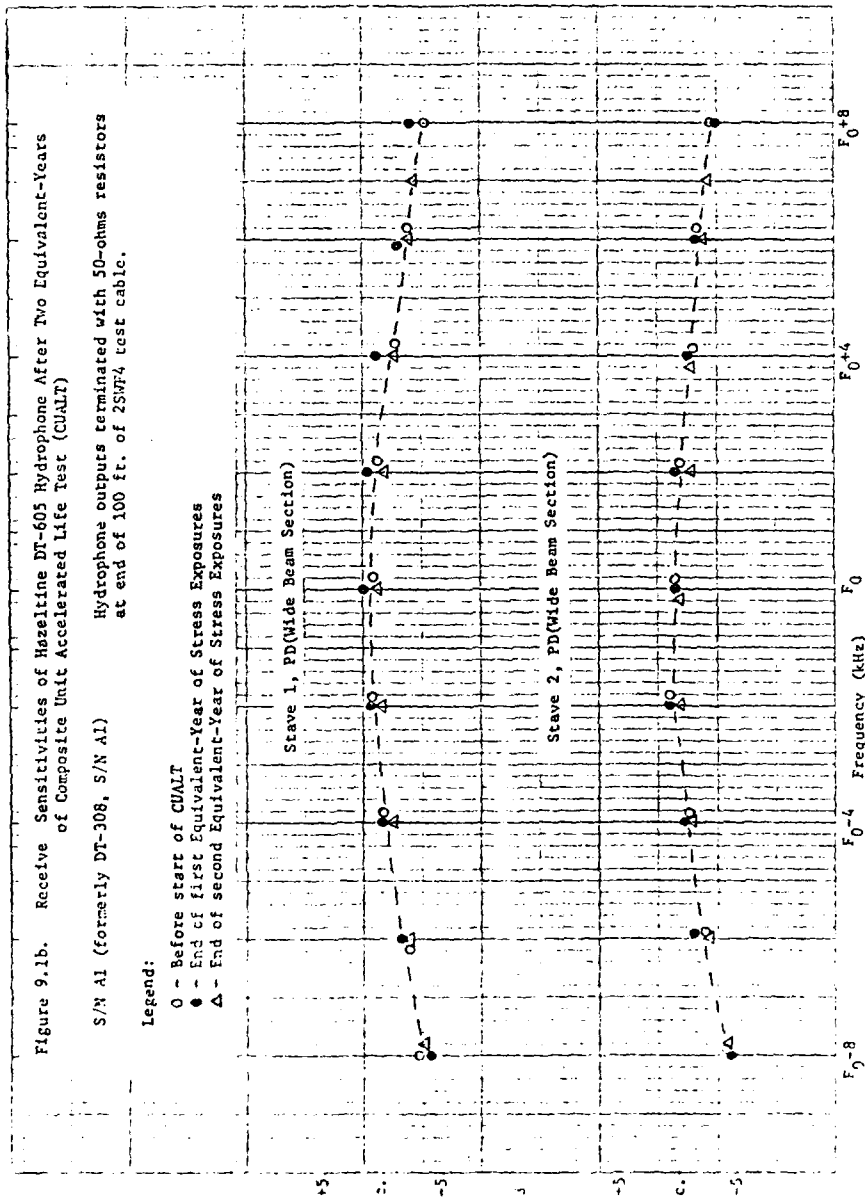
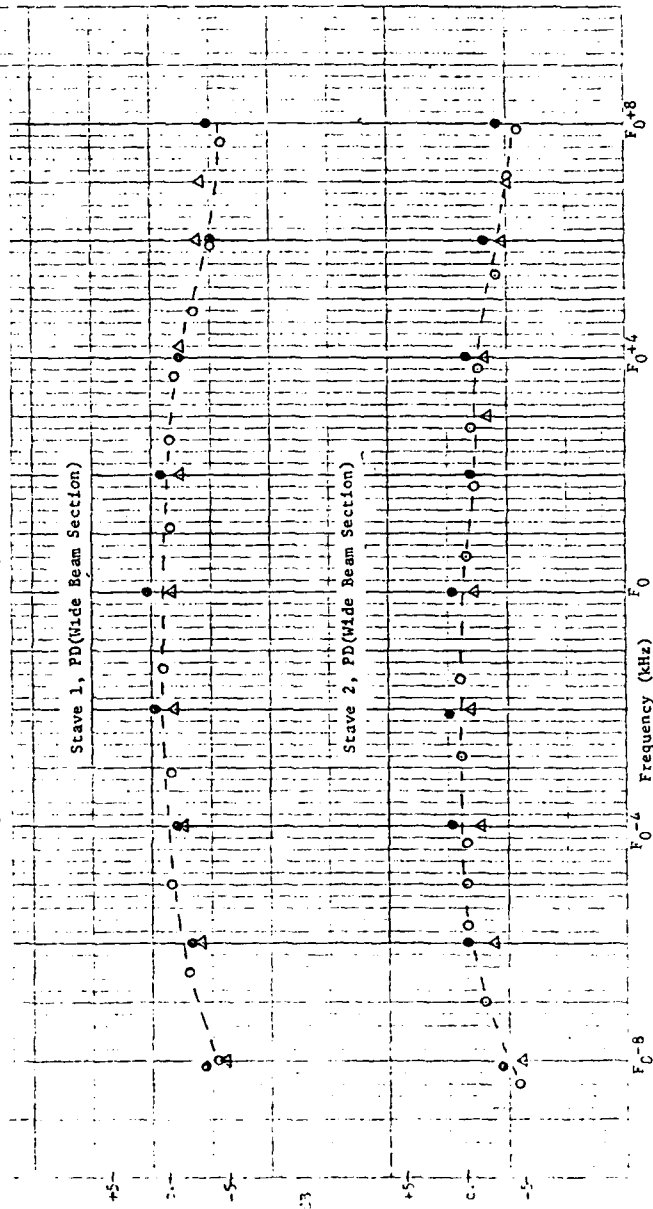


Figure 9.2b. Receive Sensitivities of Hazeltine DT-605 Hydrophone After Two Equivalent-Years of Composite Unit Accelerated Life Test (CUALT)

S/N A5 (formerly DT-308, S/N A5) Hydrophone outputs terminated with 50-ohms resistors at end of 100 ft. of 25UF4 test cable.

Legend:

- - Before start of CUALT
- - End of first Equivalent-Year of Stress Exposures
- △ - End of second Equivalent-Year of Stress Exposures



10. TASK E-2 - ACCELERATED LIFE TEST VERIFICATION

D.E. Moore - NWSC

D.J. Steele - NWSC

10.1. BACKGROUND

Composite Unit Accelerated Life Testing (CUALT) is becoming an accepted procedure for determining the production reliability and expected service period of sonar transducers. At this time no attempt has been made to determine the accuracy and validity of the CUALT concept. One approach for verifying this method is comparing the aging results of post-service transducers with those of transducers that have been exposed to the CUALT procedures.

This type of technique has proven very useful in determining the acceptability of data obtained from performing accelerated life tests (ALT) on materials. Many times it was determined that ALT was effective only for specific materials or environments and this could be true for certain transducers when performing CUALT.

10.2. OBJECTIVE

The objective of this task is to verify the accuracy of the CUALT method by comparing results with a known real-time life test.

10.3. PROGRESS

Approximately 1½ years ago a complete array of 48 DT-168B hydrophones was removed from the USS STONEWALL JACKSON (SSBN 634) and retained intact for post-service evaluation at the Naval Underwater Systems Center (NUSC) in New London, CT. This array of hydrophones had undergone extensive evaluation at NUSC before being installed in the SSBN 634. It was decided that these hydrophones could be used to verify the acceptability of using CUALT for hydrophones.

The DT-168B (Fig. 10.1) is the passive sensor for the AN/BQR-2B Sonar System. This set of 48 hydrophones was fabricated by the Naval Weapons Support Center (NAVWPNSUPPCEN) in Crane, IN, in 1972. Three sets of five air-backed cylindrical ceramics made of lead-zirconate-titanate (PZT-5A) wired in parallel series are the main internal electrical components. The ceramics are protected by a steel cage that is covered by a butyl rubber acoustic window. The elements are isolated from the cage by rubber grommets. Shielded DSS-3 cable 125-ft long is used to connect each hydrophone to the system.

By fabricating ten hydrophone units identical to those in the array and performing an established CUALT on these units it will be possible to compare the degradation of these units to the information retrieved from the post-service hydrophones.

The entire array of DT-168B hydrophones was tested at NUSC. The information obtained is being analyzed and, once completed, will be supplied to the NAVWPNSUPPCEN for further evaluation and inclusion in this project. Of these 48 hydrophones, 45 were shipped to NAVWPNSUPPCEN to be evaluated for this project. A null balance test was performed on every hydrophone and a capacitor was added in line with the cable to compensate for 60 ft of cable that had been removed during installation. Only eight hydrophones failed to pass the minimum null balance requirements established in May 1972; but the data indicated that the lowest recording was only lower by 2 dB. The fact that the loss in null balance was such a small amount shows that it would have had little influence on the acoustic performance of the sonar array. All units were also tested for capacitance, dissipation, and insulation resistance (Table 10.1).

Ten hydrophones were disassembled in order to evaluate individual components and materials. The data obtained is included in Table 10.1.

The castor oil removed from the hydrophone was discolored. Samples were then chemically analyzed. Less than .03% water and significant concentrations of inorganic compounds such as sulfate or nitrate were present in suspension. Further, chemical analysis is in progress at this time to determine the major constituents and a report will be prepared at completion.

An attempt was made to obtain the engineering and deck log of the USS STONEWALL JACKSON (SSBN 634). This was necessary to retrieve depth extremes, number of depth cycles, time duration at depth, water temperatures, and intervals of drydock. A mission profile for the DT-168B CUALT was to be generated from this information, but a letter has been received from the Commander of the Submarine Atlantic Fleet which states that the desired information is no longer available. A decision has been made to continue to attempt to produce a specialized mission profile for this submarine for the years involved by contacting other personnel. In the event that this is not successful, the SSBN mission profile developed by Texas Research Institute (TRI) will be refined and used for this project.

The parts for the new hydrophones are being fabricated and will be completed next quarter. Assembly will be initiated once all parts are received.

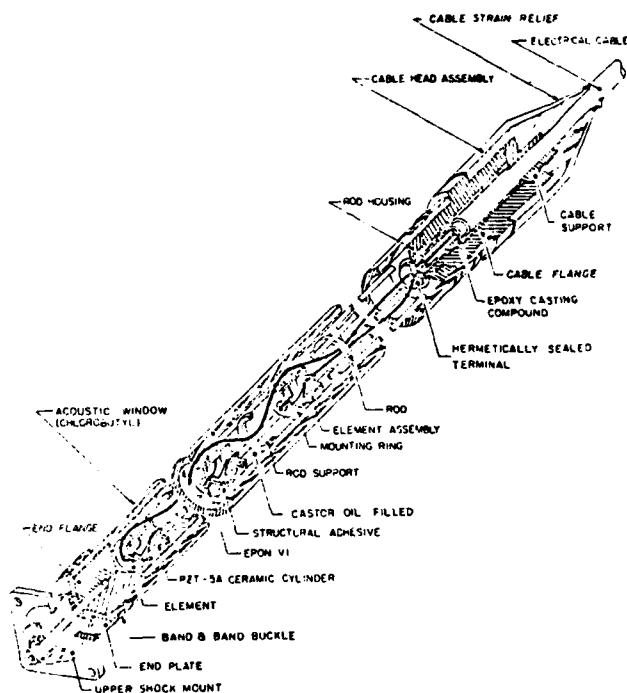


Fig. 10.1 - DT-168B Hydrophone

ELECTRICAL CHARACTERISTICS	1972 125-FT CABLE (1000 V)	1979 65-FT CABLE & CONNECTOR (500 V)
Insulation Resistance ($G\Omega$)		
Black - White	3.6	1.4
Black - Shield	5.7	10.5
White - Shield	12.4	8.9
White - Cage	1.1	.34
Black - Cage	2.1	1.1
Castor Oil ($G\Omega$)	45	3
Cable Capacitance (pF/ft)	27	28
Average Caged Ceramic Capacitance (pF)	9.7	9.1
Hydrophone Capacitance (pF)		18.57
Dissipation (d)	.017	.017

Table 10.1 - Evaluation of Ten
Disassembled Hydrophones

10.4. PLANS

- Test and evaluate additional hydrophones for insulation resistance, capacitance, cable capacitance, dissipation, and free-field voltage response.
- Complete analysis of castor oil.
- Obtain submarine environmental data or refine TRI SSBN mission profile.
- Develop a CUALT procedure.
- Build ten new hydrophones.
- Test and evaluate the hydrophones after CUALT.
- Compare the test data with that of *post-service* hydrophones for determination of CUALT reliability or effectiveness.

11. TASK F-1 - ENGINEERING ANALYSIS: FAILURE MODES DUE TO WATER

D. Barrett - Texas Research Institute (TRI)

11.1. BACKGROUND

Previous studies have developed some of the techniques of calculating the rate of water ingress into a transducer case, but more or less severe assumptions have had to be made for these calculations to date. In addition to the assumptions about the rate of water ingress, little work has been done on the effects of the ingressed water. The various failure mechanisms that can be triggered by the presence of water are not well understood and are not quantized.

11.2. OBJECTIVES

The objectives of this task are to identify and analyze the failure modes of transducers which are produced by water that has permeated into the transducer through seals, bonds, and windows.

11.3. PROGRESS

The approach will be in phases which are designed to determine what happens to water once it gets into a transducer and how it affects the lifetime of the transducer. The first phase will determine the composition of the permanent - the quantity and type of dissolved solids which come through with water, whether they are from seawater or contaminants from the elastomer. The second phase will be to test the effect of water on the lifetime functions of a transducer.

For Phase I, experiments were designed to give a qualitative evaluation of results. Thus, conductivity will be used to detect the presence of ionic, inorganic species and, if this test is positive, more detailed (spectroscopic, qualitative, and quantitative) examination will be conducted. For organic components, the first evaluation will be done by gas chromatography (GC). Following a positive indication of organic species, the detailed analyses will be by GC/MS or pyrolysis GS, if such analyses are deemed helpful at that point.

The experiment to determine the composition of permeant was an accelerated one. WRT neoprene samples were molded in slabs 12.7x10.2x0.25 cm and cut into strips 0.32-cm wide and 4.3-cm long. The total weight of rubber was 94.90 g and the total surface area was 927 cm². The cut strips were placed in a round-bottom flask with 250 ml of deionized water and a condenser; the water was heated to reflux for eight days, after which time the water was decanted and cooled.

Several observations were made: (1) the resistivity of the water changed from 94,000 ohm-cm to 53 ohm-cm; (2) a yellow solid (sulfur by flame test) collected in the condenser; and (3) a milky paste was adhering to the walls of that reaction flask.

The increase in conductivity indicates that inorganic ionic species were extracted by the water. The extract is being submitted for cation analysis by emission spectroscopy.

Organic analysis is now being done by gas chromatography. This first determination is merely a qualitative one seeking the presence of organics in water. If the test is positive, two steps remain: (1) seek the composition of the initial sample; and (2) submit the extracted residue for analysis by GC/MS or pyrolysis GC.

Finally, an experiment has been designed to determine the effect of humidity inside transducers, specifically the TR-208A element. Generally, it is as follows:

- a. Enter an element and wire it so that one can measure the internal resistance (IR) of the piezoelectric ceramic stack or so that the element can operate normally. Also, measure the internal humidity (RH) upon entry to the element.
- b. The element will be sent to NRL-USRD in Orlando, FL, for a baseline sensitivity determination.
- c. The element will be returned to TRI, rigged with gas inlet and outlet ports, and dried to 0% RH and equilibrated at this level. Then known amounts of water will be injected, allowed to equilibrate inside the element and will be measured.
- d. If an IR change is observed in step c, the element will be sent to NRL-USRD for measurements of changes in sensitivity.

11.4. PLANS

- Complete tests on composition of permeant.
- Modify eight TR-208A transducers for IR measurements and gas inlet/outlets.
- Perform tests on TR-208A with varying relative humidity — short term and accelerated long term.

- Prepare a report on the rate of water permeation into an actual transducer case.

12. TASK F-2 - TEST AND EVALUATION: SHOCK HARDENED PRESSURE RELEASE
C.R. Wilson - Westinghouse

12.1. BACKGROUND

A study recently completed by Westinghouse addressed the use of polyimide and glass-loaded polyester materials as a pressure release mechanism in the TR-155F transducer. Transducers using these pressure release materials in place of the "standard" Belleville springs were subjected to extraneous noise tests, acoustic tests, and explosive shock tests. While the noise and acoustic test results were encouraging, the pressure release configurations were not intended to withstand the rigors of explosive shock.

12.2. OBJECTIVES

The objectives of this task are to develop, test, and evaluate the effectiveness of polyimide and polyester-elastomer-glass as a shock hardened pressure release material.

12.3. PROGRESS

The government-furnished equipment TR-155F transducers were received during the past quarter. Six of the transducers were modified and retrofitted with two types of pressure release materials; three with a disc of 20% glass loaded polyester and three with a polyimide ring. The six transducers were then subjected to acoustic tests at NRL-USRD. Review of the preliminary data shows that four of the six modified transducers were within specification over the frequency, temperature, and pressure ranges of interest.

The two transducers which did not meet the specifications were both retrofitted with polyimide pressure release material and appear to have "bottomed out" at very low hydrostatic pressures. In this modified arrangement, support for the rear bulkhead is provided by a stainless steel sleeve instead of the original snap-ring. The end seal of the transducer in turn supports the steel sleeve and therefore determines the axial position of the pressure release mechanism. In the case of both failed transducers, the end seal could not be screwed all the way in because of thread damage. That is, the pressure release "bottomed out" because it was never all the way "in." Two additional transducers have been modified with the polyimide pressure release and resubmitted for acoustic tests.

The one polyimide retrofitted transducer which has undergone complete acoustic performance evaluation did not meet the specification for free-field voltage sensitivity in the area of the low-frequency resonance. The compliance of the pressure release mechanism caused a

shift in the frequency of the low-frequency resonance. No attempt has been made to alter the compliance of the polyimide pressure release.

Six transducers (three of each type) will undergo extraneous noise tests at NWSC, Crane, beginning in early April 1980. The explosive shock test at Hunter's Point, CA, has been postponed until 14 July 1980. Two transducers (one with each type of pressure release material) will be included in that test.

12.4. PLANS

Acoustic tests of the two resubmitted transducers will be completed at the earliest possible date. The extraneous noise test should be completed by early May 1980. The delay in the explosive shock test will extend the completion of this work until mid-August 1980.

13. TASK F-3 - RELIABILITY AND LIFE PREDICTION SPECIFICATION

R.L. Smith - Texas Research Institute

D.D. Barrett - Texas Research Institute

13.1. BACKGROUND

The reliability and life requirements for wet and sonar equipment must have better definition; present reliability prediction methods do not adequately account for redundancy, and current life prediction methods are subjective. Improvements in reliability and life definition and prediction are needed for STRIP objectives to be met, for example MTBF does not uniquely specify the reliability in the time frame of interest which is the first few years of service. Other factors, such as the definition of failure, and the use of redundancy in the design dominate the reliability versus time relationships. Specifying life in years does not handle the problem of shelf life nor does it uniquely specify wearout reliability.

The present approach used by the Navy for wet and sonar equipment procurements is to specify numerical reliability and life requirements in the Critical Item Procurement Specification (CIPS) and to have the contractor achieve these requirements through a reliability program described in attachment 2 to the contract. Unfortunately, for the reasons given above, a contractor can fulfill all the requirements as currently stated and still deliver unreliable, short-lived hardware.

13.2. OBJECTIVES

The ultimate objective is to improve the specificity of the Navy specifications for reliability and life requirements (CIPS) and reliability achievement programs (attachment 2 to the standard procurement package). The intermediate objectives are:

1. Learn how to analyze the superposition of random and wearout reliabilities.
2. Learn how to extract wearout failure mechanisms and random failure hazards from an FMEA.
3. Learn how to put a time scale on the wearout failure mechanisms vis-a-vis actuation energies, stress amplitudes and cycling, etc.
4. Learn how to do a life prediction.
5. Improve present (random) reliability prediction methods by correct analysis of redundancy and definitions of failure.

6. Learn how to superimpose the results of 4 and 5.
7. Learn how to handle subjective information.
8. Figure out how the contractor can achieve the predicted overall reliability (random and life) with appropriate contractor-managed reliability achievement programs (critical parts management, piece-part testing, compatibility studies, QC inspection, design reviews, etc.).

13.3. PROGRESS

This is a new task for FY80 which is being performed under contract N00024-79-C-6232 by Texas Research Institute, Inc. The approach for FY80 is to complete intermediate objective 1 above and to complete a portion of objective 5, specifically, to examine the effects of uncertainties in data used in the failure rate model and determine the dispersion in the resultant reliability estimates.

The main effort during this quarter has been formulation of the program in detail. Table 13.1 lists the areas of consideration in the program formulation and Table 13.2 lists the conclusions at this early point.

The question of superposition of wearout and random failure is a textbook problem; we have been looking at the possibilities of using curve fitting techniques to be able to determine if a population is exhibiting wearout or random failures. One point that must be addressed is the size of the sample needed in order to achieve adequate confidence in the result; it may be that the sample size must be too large for curve fitting to be a feasible approach for sonar wet end components. If that is the case, then failure analysis may be the approach best suited to those systems.

During this quarter, we were requested by NAVSEA to provide some paragraphs to be used in the reliability section of a procurement specification for sonar transducers. That effort directly relates to the overall charter and was completed under this task.

13.4. PLANS

A visit to TRI, scheduled for 28 April 1980, by C.A. Clark of NAVSEA and Dr. G. Kinnison of NOSC. Progress to date and program plans will be discussed during that visit. A number of program structure questions will be handled at that meeting, after which the problems of wearout and data spread will be addressed.

Dr. Smith will attend the Reliability and Testing Institute in Tucson, AZ, during 14-18 April 1980 in the company of personnel from NRL-USRD and NUSC-NLL. This institute is oriented such that it is directly applicable to these tasks. New insights from that institute will be incorporated into the models being developed.

- I. MATHEMATICAL BACKGROUND
 - A. Sonar Reliability Functions and Interrelationships
 - B. Random Hazard Case — Exponential Reliability
 - C. Normally Distributed Times to Failure — Wearout
 - D. The Binomial Distribution
 - E. Distribution Moments
- II. RELIABILITY PREDICTION (PRELIMINARY EVALUATION)
 - A. Building on Cataloged Components' Level Experience — Handbook Method
 - B. Inferences Based on Materials Properties — Probabilistic Design
 - 1. Overlap of Stress and Strength Distributions
 - 2. Distribution Synthesis
 - 3. Numerical Methods — Monte Carlo Simulation
 - C. Scope, Limitations, Practical Difficulties
 - D. Reliability Assessment (Post Evaluation)
- III. LIFE PREDICTION (ESTIMATION) — WEAROUT
 - A. Identify the Failure Modes and Life Limiting Process
 - B. Characterize the Environmental and Service Stresses
 - C. Calculate the Time Scale of Accumulated Damage
 - D. Limitations and Difficulties
 - 1. Poorly Defined Stresses and Endpoints
 - 2. Synergistic Effects
 - 3. Time Scale — Cost
- IV. SPECIAL DIFFICULTIES AND THE PRIMITIVE STATE OF NAVY SONAR RELIABILITY WORK
 - A. Heroic Time Scale — Cost
 - B. Gaps in the Quality and Kind of Hazard Rate Data
 - C. Need to Define Systems Operating Requirements
 - D. Undefined Process Endpoints — Permeation Example
 - E. Test Method Nonuniformity
 - F. Need for Systematic and Uniform Data Acquisition
- V. FY80 TASKS
 - A. Distinguishing Chance and Wearout Failure
 - B. Characterizing the Dispersion of Handbook Reliability
- VI. FUTURE NEEDS
 - A. Time-to-Failure Data
 - B. Postmortem Studies of Failed Transducers
 - C. Serious Commitment to Excellence at all Levels

Table 13.1 - Reliability and Service Life Concepts

1. Reliability theory is mature and well developed.
2. Theory is not a substitute for real-life observational data; rather, it is a tool for characterizing such information.
3. There is no substitute for direct or closely related hardware experience in evaluating reliability.
4. Time-to-failure information is of particular interest.
5. Sonar reliability is especially challenging because of the heroic time scale involved.
6. There is reason for optimism — the fleet is already available as a potentially grand reliability experiment.
7. Closer interdisciplinary cooperation is in order — scientists need to address practical, bottom-line issues; managers need to identify and pursue fruitful avenues of investigation.
8. Sonar reliability is a big problem and will yield its benefits only to a big commitment to success. This involves time and money but more importantly, the dedicated efforts of individuals who take pride in their work.

Table 13.2 - Conclusions

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2. R.W. Timme, "Sonar Transducer Reliability Improvement Program FY79 Fourth Quarter Progress Report," NRL Memorandum Report 4058 (1979)
3. J.M. Meek and J.D. Craggs, Electrical Breakdown of Gases, Wiley-Interscience, NY, pp 558 (1978)

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